Usefulness of Non-Invasive Right Ventricular Function Assessment in Prediction of Adverse Events after Successful Balloon Mitral Valvuloplasty

Ragab A, Mahfouz, MD, Mohamed Abdou, MD, Amr Abdelmoneim, MD and Tamer Mostafa, MD

Cardiology Department, Faculty of Medicine, Zagazig University, Egypt

ABSTRACT

Background and aim: Right ventricular (RV) function usually affects the outcome in valvular heart disease but much less is known about the impact of RV function on the clinical outcome after successful percutaneous balloon mitral valvuloplasty (PBMV). So,this study was designed to evaluate RV function in patients with mitral stenosis and its effect on the long-term outcome after successful PBMV .**Methods and results**:147 patients with isolated rheumatic mitral stenosis and candidate for PBMV were included in this study matched with 65 control.Patients mean age was 30 ± 13 years and 106 were female. All of them were in sinus rhythm. Tricuspid annular plane systolic excursion (TAPSE), a parameter of RV longitudinal function was assessed by conventional echocardiography, while Sm, Em and Am velocities of tricuspid valve annulus were assessed by tissue Doppler imaging echocardiography. Two groups were formed based on the development of adverse events during 42 ± 14 months follow-up (AF, progressive pulmonary hypertension, worsening NYHA class, re-stenosis and stroke) . Group I those with events (n=45) and group II, those without events (n=102). The results showed that TAPSE ,Sm,and Em/Am conformed to RV function were significantly reduced in patients group compared to control . One-day after successful PBMV,TAPSE increased from 17.11 ± 2.1 mm to 19.13 ± 2.59 mm (P < 0.05) ,Sm increased from 11.29 ± 1.6 cm/s to 13.26 ± 1.37 cm/s (P<0.05) ,and Em/Am ratio increased from 1.15 ± 0.12 to 1.47 ± 0.19 (P < 0.05). There was a significant impairment of RV function among patients who developed adverse events compared to those without events on follow-up (TAPSE was 14.59 ± 0.21 mm vs 18.13 ± 2.59 mm ,P < 0.04, Sm was 9.8 ± 0.22 cm/s vs 12.26 ± 1.37 cm/s, P<0.04 and Em/Am ratio was 0.91 ± 0.58 vs 1.62 ± 0.32, P<0.01). ROC curve analysis of TAPSE, Sm, and Em/Am in prediction of adverse outcome after successful PBMV showed worse outcome with TAPSE <15 mm, Sm <10 cm/s, Em/Am ratio< 0.9.
Conclusion: RV dysfunction was observed in all cases of MS irrespective of the degree of pulmonary hypertension. TAPSE and tricuspid annulus tissue Doppler indices were able to assess RV dysfunction in patients with similar degrees of MS and to precociously recognize patients with worse prognosis.

Key Words: Mitral stenosis, Right ventricle function, Percutaneous balloon mitral valvuloplasty, Tissue Doppler echocardiography, Tricuspid annular plane systolic excursion.

INTRODUCTION

Mitral stenosis (MS) still results in significant morbidity and mortality worldwide [1,2] . Type of treatment, as well as its timing, should be decided on the basis of clinical, morphological, and functional characteristics [3]. Although there is clear indication to surgically or percutaneously treat MS in symptomatic patients, for the asymptomatic ones, there is agreement to treat only in the presence of pulmonary hypertension [4]. These patients may feel asymptomatic for years and often present only a gradual decrease in their activity [3]. So a

---

*Corresponding Author: Dr. Mohamed Abdou (MD), Cardiology Department, Faculty of Medicine, Zagazig, Egypt.

diagnostic tool, capable to evaluate asymptomatic patients who are at risk of adverse events, may be very useful.

The function of right ventricle (RV) has been poorly investigated in valvular heart disease, and particularly so in cases with rheumatic etiology. It has been established that RV function can be impaired in valvular heart disease [5] and be a major determinant of clinical outcome as well [6] .

AIM OF THE STUDY

To evaluate RV function non-invasively using tricuspid annular plane systolic excursion (TAPSE) and tricuspid annular velocities tissue Doppler imaging (TDI) in patients with mitral stenosis and the prognostic impact of RV function on the late clinical outcome after successful percutaneous balloon mitral valvuloplasty (PBMV).

MATERIALS AND METHODS

A total of 147 patients with mitral stenosis of rheumatic origin fulfilling the criteria for PBMV were included in the study. Exclusion criteria: (1) more than mild mitral insufficiency,(2) concomitant hemodynamically significant valvular disease ,(3) bad quality echocardiographic imaging ,(4) any disease that could affect myocardial function (e.g. coronary artery disease, chronic lung disease, cardiomyopathies),and (5) atrial fibrillation or atrioventricular conduction abnormalities .

Sixty five age- and sex-matched healthy subjects were also enrolled as the control group.

PBMV:

All procedures were performed by the anterograde trans-septal approach. A double balloon stepwise technique was used in all patients under fluoroscopy guidance. A successful PBMV was defined as an MVA $\geq$1.5 cm^2 or $\geq$1 cm^2/m^2 with no regurgitation >2/4.

Echocardiography:

The machine used was Hp Sonos -5500 transthoracic ultrasound system with a phased-array transducer of 2.5 MHz. Echocardiographic examinations, including M-mode, two-dimensional (2D), pulsed and color Doppler ,and TDI , were recorded before and in the next day after PBMV and analyzed off-line.Measurements were done and evaluated according to recent guidelines [7].

The following measures were selected for analysis:

1- Left atrial diameter (LAD): by M-mode and 2-D measurements.
2- Mitral valve area (MVA): 2D views of the mitral valve were obtained from the parasternal short axis window and planimetry was performed. Continuous-wave Doppler recordings through the mitral valve were obtained from the apical four-chamber window and MVA was estimated by using the formula 220/PHT [8]. Three cardiac cycles were recorded and their results averaged for every patient.
3- LV systolic function parameters:
   End systolic (LVESD) and end diastolic (LVEDD) diameters and volumes (ESV and EDV) were calculated and hence EF % and FS% were measured by M-mode and biplane Simpson technique [9].
4- Right ventricular end diastolic diameter (RVIDd) was measured along the minor axis in the apical four-chamber view, at a level of approximately one-third above the tricuspid annular plane.
5- Systolic pulmonary artery pressure (SPAP): The maximal tricuspid regurgitation (TR) velocity was recorded by continuous-wave Doppler and SPAP was calculated using the modified Bernoulli equation, after estimating right atrial pressure (RAP). Values of SPAP $\geq$ 35 mmHg defined pulmonary hypertension [10].
6- RV function was evaluated by:
   a) Tricuspid annular plane systolic excursion (TAPSE) as a parameter for RV long axis function :was assessed with M-Mode using the 2D apical four-chamber view .The cursor was placed through the lateral tricuspid annulus in real time. Off-line, the brightness was adjusted to maximize the contrast

between the M-mode signal arising from the tricuspid annulus and the background. TAPSE was measured as the total displacement of the tricuspid annulus in millimeters from end-diastole to end-systole (Figure 1), whereas data were averaged over five beats as it has been recommended [11].
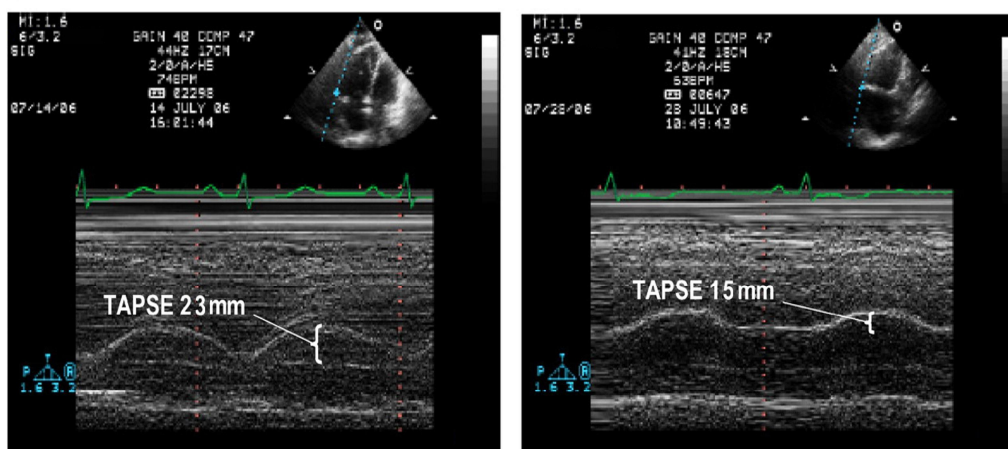

Figure (1):M-mode through lateral TV annulus to measure the TAPSE.Left one from subject with normal RV function ,the 2nd picture from patient with RV dysfunction.

b- Pulsed Doppler tissue imaging techniques (TDI): were used for estimation of tricuspid annular systolic and diastolic velocities, after placing the cursor at the junction of the right ventricle free wall and the anterior leaflet of the tricuspid valve, using the 2D four-chamber view. The peak systolic (Sm), peak early diastolic (Em), and peak late diastolic (Am) annular velocities were calculated and averaged over three consecutive beats , as it has been previously described [12].

Follow-up:

Was done for all patients for a mean period of 42 ± 14 months at 6 months interval and or upon development of any symptoms .The follow-up visits included complete history taking and thorough clinical examination, electrocardiogram as well as complete echo-Doppler assessment.
Patients were classified into two groups according to the development of adverse events along the period of follow-up. Group I, included those who developed adverse events and group II included those without adverse events.

STATISTICAL ANALYSIS

All the analyses were performed using a commercially available package (SPSS, Rel. 11.0, 2002, SPSS Inc., Chicago). To compare MS patients vs. control, or MS patients who developed events vs. MS patients without events, the unpaired Student's *t*-test was performed for continuous variables, whereas for categorical variables, Fisher's exact test was used. Quantitative values were presented as mean ± standard deviation (SD). Relation between quantitative variables was studied using the linear regression. In the search for a diagnostic cut-off value for occurrence of adverse events at follow-up, a receiver operating characteristic (ROC) curve analysis was constructed and the area under the curve was reported, which is representative of the discriminatory ability of the variable cut-off. Sensitivity and specificity, positive and negative predictive values of the best cut-off variable were calculated. A *P*-value of <0.05 was considered statistically significant [13,14] .

RESULTS

In patients with MS, pulsed TDI systolic and diastolic tricuspid annular indices and TAPSE as well (parameters of RV function) were significantly reduced compared to control group (Table 1).

Table 1: Clinical, echo Doppler, and tricuspid annular TDI data of both patients and control groups

Parameter	MS patients ($N = 147$)	Control ($N = 65$)	*P*-value
Age (years)	30 ± 13	31± 12	>0.9
Sex (M/F)	41/106	18/43	>0.9
BSA (m^2)	1.72 ± 0.2	1.76 ± 0.3	>0.9
HR (bpm)	84 ± 17	79 ± 13	>0.9
SBP (mmHg)	115 ± 9	119 ± 12	>0.9
DBP (mmHg)	72 ± 9	73 ± 6	>0.9
MVA (cm^2) Planimetry PHT	0.83 ± 0.21 0.92 ± 0.29	--- ---	
TMG (mmHg) Mean Maximum	18.7 ± 10.4 27.9± 13.5	--- ---	
LA D(mm)	49.4 ± 3.6	34 ±3	<0.0001
LVEDD (mm)	45.5 ± 4.3	44.9 ±3.9	>0.05
LVESD (mm)	29.7 ± 3.5	29 ± 2.6	>0.05
LVEF (%)	74.2 ± 7.6	76.3 ± 4.6	>0.05
RVDD(mm)	22.5 ± 2.2	17 ± 4	<0.05
SPAP (mmHg)	46.9± 28.6	21± 5	<0.0001
TAPSE (mm)	17.11 ± 2.1	24.9 ± 3.1	<0.003
Sm (cm/s)	11.29 ±1.6	16.42 ± 0.4	<0.001
Em/Am ratio	1.15 ± 0.12	1.92 ± 0.24	<0.001

TDI tissue Doppler indices ,BSA body surface area , HR heart rate ,SBP systolic blood pressure ,DBP diastolic blood pressure , MVA mitral valve area ,TMG transmitral gradiant , LAD left atrial diameter ,LVEDD left ventricular end diastolic diameter, LVESD left ventricular end systolic diameter, LVEF% Left ventricular ejection fraction, RVDD right ventricular diastolic diameter ,SPAP systolic pulmonary artery pressure ,TAPSE tricuspid annular plane systolic excursion , Sm peak systolic myocardial velocity.

There was significantly decreased SPAP with significantly increased TAPSE and pulsed TDI systolic and diastolic tricuspid annular indices after significantly increased MVA one-day after PBMV (Table 2).

Table 2: Conventional echocardiographic and TDI data before and one-day after percutaneous balloon mitral valvuloplasty

Variable	Before PBMV	After PBMV	*P*-value
LAD (mm)	49.4 ± 3.6	43.3 ± 4.83	<0.004
LVEDD (mm)	45.5 ± 4.3	46.2 ± 5.8	>0.05
LVESD (mm)	29.7 ± 3.5	30.4 ± 5.7	>0.05
LVEF (%)	74.2 ± 7.6	63.3 ± 11.1	>0.05
RVDD (mm)	22.5 ± 2.2	21.8 ± 2.5	>0.05
MVA (cm^2) Planimetry PHT	0.83 ± 0.21 0.92 ± 0.29	1.99 ± 0.49 1.82 ± 0.29	<0.0001 <0.0001
TMG (mmHg) Mean Maximum	18.7 ± 10.4 27.9 ± 13.5	5.6 ± 1.7 9.2 ± 3.3	<0.001 <0.0001
SPAP (mmHg)	46.9 ± 28.6	28.6 ± 11.2	<0.02
TAPSE (mm)	17.11 ± 2.1	19.13 ± 2.59	< 0.05
Sm (cm/s)	11.29 ±1.6	13.26 ±1.37	<0.05
Em/Am ratio	1.15 ± 0.12	1.47 ± 0.19	<0.05

TDI tissue Doppler indices ,MVA mitral valve area ,TMG transmitral gradiant , LAD left atrial diameter ,LVEDD left ventricular end diastolic diameter, LVESD left ventricular end systolic diameter, LVEF% Left ventricular ejection fraction, RVDD right ventricular diastolic diameter ,SPAP systolic pulmonary artery pressure ,TAPSE tricuspid annular plane systolic excursion , Sm peak systolic myocardial velocity.

Out of 147 patients with isolated MS, 45 (30.6%) developed adverse events after 42±14 months period of follow-up as follow: 19 (42.2%) patients developed persistent AF, 21 (46.7%) patients became symptomatic (NYHA class III) with SPAP >50 mmHg, 2 (4.4%) patients underwent PBMV for restenosis, 3 (6.7%) patients developed stroke (one case with associated dense spontaneous contrast in LA and the other two cases associated with recent paroxysmal AF). The demographic and echocardiographic variables of patients with adverse events on follow-up compared to those without events are given in Table 3.

Table 3: Baseline clinical, echoDoppler, and tricuspid annular TDI data of patients who developed adverse events vs those without events during follow-up

Parameter	MS patients with adverse events (*N*= 45)	MS patients without adverse events (*N* = 102)	*P*-value
Age (years)	31 ± 14	29.5 ± 12	0.13
BSA (m^2)	1.69 ± 0.12	1.72 ± 0.1	0.8
HR (bpm)	84 ± 17	83 ± 14	0.9
SBP (mmHg)	118 ± 11	112 ± 14	0.7
DBP (mmHg)	74 ± 7	72 ± 5	0.8
MVA (cm^2) Planimetry PHT	0.85 ± 0.19 0.97 ± 0.21	0.91 ± 0.13 0.99± 0.22	0.26 0.12
TMG (mmHg) Mean Maximum	17.5 ± 9.9 26.2± 11.3	18.3 ± 12.5 26.8 ± 12.7	0.34 0.56
LA D(mm)	51.2 ± 4.9	49.7 ± 5.2	0.42
LVEDD (mm)	46.1 ± 6.6	45.4 ± 6.2	0.63
LVESD (mm)	30.2 ± 5.9	29.6 ± 5.3	0.7
LVEF (%)	69.8 ± 8.8	74.3 ± 12.7	0.45
RVDD (mm)	23.5 ± 2.1	22.4 ± 2.3	0.09
SPAP (mmHg)	48.5± 31.4	47.2 ± 33.6	0.8
TAPSE (mm)	14.59 ± 0.21	18.13 ± 2.59	<0.04
Sm (cm/s)	9.8 ± 0.22	12.26 ±1.37	<0.04
Em/Am ratio	0.91 ± 0.58	1.62 ± 0.32	<0.01

TDI tissue Doppler indices ,BSA body surface area , HR heart rate ,SBP systolic blood pressure ,DBP diastolic blood pressure , MVA mitral valve area ,TMG transmitral gradient , LAD left atrial diameter ,LVEDD left ventricular end diastolic diameter, LVESD left ventricular end systolic diameter, LVEF% Left ventricular ejection fraction, RVDD right ventricular diastolic diameter ,SPAP systolic pulmonary artery pressure ,TAPSE tricuspid annular plane systolic excursion , Sm peak systolic myocardial velocity.

ROC curve analysis was performed to calculate the cut-off value to predict adverse clinical outcome after successful PBMV (Table 4).

Table (4): ROC curve analysis of tricuspid annular plane systolic excursion (TAPSE) , tricuspid annular (Sm) velocity, and Em/Am ratio in predition of adverse outcome after successful PBMV

Variable	Cut-off value	AUC	Sensitivity	Specificity
TAPSE	15 mm	0.885	97%	75%
Sm	10 cm/s	0.890	93%	62%
Em/Am	0.90	0.895	0.91	0.64

ROC receiver operating characteristic, AUC area under the curve

DISCUSSION

In patients with mitral stenosis, RV function is closely related to symptoms, functional capacity, need and timing for interventions, perioperative mortality, and postoperative results [15]**.**
Evaluation of RV function by conventional transthoracic echocardiography is difficult due to its asymmetrical shape, narrow acoustic window, and geometrical assumptions for calculation of volumes [16].So, recently,

alternative techniques have been proposed, including tissue Doppler imaging (TDI) which measure velocities of cardiac tissue and reflect directly myocardial function and considered a promising technique for evaluating RV function [17] **.**For example , many studies has been shown Sm to reflect RV systolic function. This parameter was found to have a very good correlation with RV fractional area and RVEF assessed by radionuclide ventriculography [18]. Also, tricuspid annular Em and Am may be used for the detection of RV diastolic pathology in isolated mitral stenosis [19].

Another parameter, TAPSE, showed an excellent correlation with RV ejection fraction calculated using echocardiography [20] or radionuclide angiography [21] ,and its measurement has been proven to be highly reproducible and easy to obtain [22].

In our study ,all patients with MS revealed significantly decreased TAPSE and tricuspid annular TDI Sm velocity and Em/Am ratio compared to age- and sex-matched controls ($p<0.003$) denoting that the RV function is usually impaired (even subclinical) in those patients spite of mild pulmonary hypertension. In accordance with these results, Drighil, et al [23] suggested that patients with MS have depressed global and regional RV function compared with normal subjects; findings go hand in hand with previous radionuclide [24] and haemodynamic studies [25].

Diastolic functions of RV may deteriorate in the presence of normal systolic functions in symptomatic patients with isolated mitral stenosis [19]. Good correlation between RV diastolic dysfunction (and not systolic dysfunction) and increased pulmonary artery systolic pressure has been demonstrated indicating RV systolic dysfunction to be the result of pulmonary hypertension, disturbance of myocardial microcirculation and myocardial fibrosis. These findings suggest that RV diastolic dysfunction is the first detectable myocardial manifestation of inflammatory process [26].

The reasons for this impaired RV function in pure MS are controversial [27]. Some authors speculate that the rheumatic pathologic process may directly affect the myocardium to cause dysfunction [28, 29]. Malhotra et al [29] ,in a histo-morphological study of cases with rheumatic heart disease, found that intramyocardial branches of coronary vessels were involved in a form of active rheumatic vasculitis or inactive lesions characterized by medial hypertrophy and replacement fibrosis. They speculated that these changes might affect myocardial function. Also, the passive increase in left atrial pressure and reactive changes in pulmonary arteriolar resistance may lead to increased RV afterload and RV failure [30].

Our findings revealed that TAPSE and tricuspid annular pulsed TDI showed significant improvement after successful PBMV ,like the study of Sreeram et al [31] who found significant improvement in RV Sm and Em whereas RV Am was relatively unaltered and conclude that pure MS affects the long-axis function of the LV and RV, and the extent of involvement seems to correlate with MVA and the adequacy of the result of PBMV .On the other hand Mehta et al [32] noticed non significant increase in RV free wall annular velocities in 25 Pts studied Following PBMV and concluded that RV dysfunction persists in the period immediately following PBMV despite significant changes in pulmonary artery pressures, and this could explain the persistence of right sided congestion in some of these patients. The difference noticed between this study and our results may be linked to the small number of patients in the study of Mehta et al [32]. Prior investigations showed that depressed TAPSE is an adverse prognostic indicator in patients with dilated cardiomyopathy [11] , and in subjects after acute inferior myocardial infarction [33] .Also, a TAPSE of less than 1.8 cm was associated with greater RV systolic dysfunction and 50 % survival estimates at 2 years in patients with pulmonary arterial hypertension [34] .However, the current results may be the first to demonstrate the prognostic significance of TAPSE in patients with mitral stenosis after successful PBMV.Cruz-Gonzalez [35], postulated that clinical, anatomic, and hemodynamic variables predict PBMV success and clinical outcome and may be formulated in a scoring system that would help to identify the best candidates for PBMV. Several important prognostic factors have been identified PBMV. Older age, less favorable anatomy (valve calcifications, severe subvalvular disease, echocardiography score), long-lasting disease (previous commissurotomy, atrial fibrillation, NYHA functional class IV, high systolic pulmonary artery pressure, severe tricuspid regurgitation), and less satisfactory immediate results (low post-procedure MVA and high post-procedure mean transmitral gradient) have been uniformly associated with a worst outcome [36,37] **.** In our study ,TAPSE and tricuspid annular TDI parameters can be added to the previous prognostic factors as they were significantly reduced in patients who developed adverse events during follow-up and had a higher predictive power with the best AUC for detection of adverse clinical outcome after successful PMBV. A TAPSE < 15mm and Sm < 10 cm/s predicted clinical outcome in those patients with considerable sensitivity and specificity. Spite of successful PBMV,these abnormal right ventricular indices may reflect a significant degree

of atrial fibrosis and stiffness as well as RV subclinical myopathy that could contribute to the development of atrial fibrillation and other cardiac events. Again,the indication for intervention, either percutaneous or surgical, depends on symptoms, pulmonary artery pressure, and RV function in patients with MS [38] and right ventricular dysfunction is an important indicator to evaluate the severity of mitral stenosis [39] .

It is more complicating to decide the need and timing for intervention in MS patients without clinical signs of systemic venous congestion, because RV functions may be impaired before the appearance of clinical signs. Therefore, evaluation of RV systolic function is important in this group of patients. So, TAPSE and tricuspid annular TDI parameters may be used as an accurate, non-invasive parameters for assessment of RV systolic function in patients with mitral stenosis especially to detect early systolic dysfunction.

Conclusion

This study demonstrated that right ventricular functions are abnormal in patients with MS even with mild pulmonary hypertension. TAPSE and RV tissue Doppler indices are able to assess early RV dysfunction in patients with similar degrees of MS and to precociously recognize patients with worse prognosis specially after successful PBMV. They may be used as an adjunctive to the currently identified predictors, with definite cutoff points, to determine the severity of MS, helping decide the indication and timing for intervention especially in asymptomatic cases with no or mild pulmonary hypertension and before development of RV dysfunction, severe TR, or advanced heart failure.

Acknowledgement

REFERENCES

1. Soler-Soler J, Galve E. Worldwide perspective of valve disease. Heart 2000; 83:721-5.

2. Baron G, Butchart EG, Delahaye F, Gohlke-Bärwolf C,Levang OW, et al. A prospective survey of patients with valvular heart disease in Europe: the Euro Heart Survey on Valvular Heart Disease. Eur Heart J 2003;24:1231-43.

3. Vahanian A, Baumgartner H, Bax J, Butchart E, Dion R, Filippatos G, et al. Guidelines on the management of valvular heart disease: the Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology. Eur Heart J 2007;28:230-68.

4. Bonow RO, Carabello BA, Chatterjee K, de Leon AC Jr, Faxon DP, Freed MD, et al. American College of Cardiology/American Heart Association Task Force on practice guidelines. J Am Coll Cardiol 2008;52:e1-142.

5. Nagel E, Stuber M, Hess OM. Importance of the right ventricle in valvular heart disease. Eur Heart J 1996;17:829–836.

6. de Groote P, Millaire A, Foucher-Hossien C, Nugue O, Marchandise X, Ducloux G, Lablanche JM. Right ventricular ejection fraction is an independent predictor of survival in patients with moderate heart failure. J Am Coll Cardiol 1998;32:948–954.

7. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, Picard MH,et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr.2005; 18: 1440–1463.

8. HatleL, Angelsen B, Tromsdal A. Non-invasive assessment of atrioventricular pressure-half-time by Doppler ultrasound. Circulation.1979;60:1096-1104.

9. Slama M, Maizel J. Echocardiographic measurements of ventricular function. Curr Opin Crit Care Med. 2006;12:241–248.

10. Yock PG, Popp RL. Noninvasive estimation of right ventricular systolic pressure by Doppler ultrasound in patients with tricuspid regurgitation. Circulation. 1984;70:657–662 .

11. Ghio S, Recusani F, Klersy C, Sebastiani R, Laudisa ML, Campana C, Gavazzi A, Tavazzi L. Prognostic usefulness of the tricuspid annular plane systolic excursion in patients with congestive heart failure secondary to idiopathic or ischemic dilated cardiomyopathy. Am J Cardiol. 2000;85:837–842.

12. Waggoner AD, Bierig SM. Tissue Doppler imaging: a useful echocardio-graphic method for the cardiac sonographer to assess systolic and diastolic ventricular function. J Am Soc Echocardiogr. 2001;14(12):1143–1152.

13. Metha C, Patel N. Exact logistic regression: theory and examples. Stat Med 1995;14:2143-60.

14. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristics (ROC) curve. Radiology 1982;143:29-36.

15. Tayyareci Y, Tayyareci G, Nişancı Y, Umman B , et al. Evaluation of the severity of mitral stenosis with a new index: isovolumic myocardial acceleration .Arch Turk Soc Cardiol 2008;36(6):388-3.

16. Levine RA, Gibson TC, Aretz T, Gillam LD, Guyer DE, King ME, et al. Echocardiographic measurement of right ventricular volume. Circulation 1984;69:497-505.

17. Xiang-dong Y, Zhao-xia P, Xian-jing P , et al., Tissue Doppler imaging study of right ventricular myocardial systolic activation in subjects with pulmonary arterial hypertension. Chin Med J 2007;120(13):1172-1175.

18. Harada K, Toyono M, Yamamoto F. Assessment of right ventricular function during exercise with quantitative Doppler tissue imaging in children late after repair of tetralogy of Fallot. J Am Soc Echocardiogr. 2004; 17:863-9.

19. Saricam E, Ozbakir C, Yildirim N, Tufekcioglu O, Ocal A, Bascil S, Bozboga S.Evaluation of the relationship between functional capacity and right ventricular diastolic function in patients with isolated mitral stenosis and sinus rhythm: a tissue Doppler study.Echocardiography. 2007 Feb;24(2):134-9 .

20. Kaul S, Tei C, Hopkins JM, Shah PM. Assessment of right ventricular function using two-dimensional echocardiography. Am Heart J 1984;107: 526–531.

21. Ueti OM,Camargo EE ,Ueti Ade A, de Lima-Filho EC, Nogueira EA. Assessment of right ventricular function with Doppler echocardiographic indices derived from tricuspid annular motion: comparison with radionuclide angiography.Heart 2002;88:244-248 .

22. Lamia B, Teboul JL, Monnet X, Richard C, Chemla D. Relationship between the tricuspid annular systolic excursion and right and left ventricular function in critically ill patients.Intensive Care Med. 2007;33:2143–2149.

23. Drighil A , Bennis A, Mathewson WJ, Lancelotti P, and Rocha P. Immediate impact of successful percutaneous mitral valve commissurotomy on right ventricular function. Eur J Echocardiogr 2008; 9 (4): 536-541.

24. Cohen M, Horowitz SF, Machac J, Mindich BP, Fuster V. Response of the right ventricle to exercise in isolated mitral. Am J Cardiol. 1985;55: 1054-8.

25. Mohan JC, Sengupta PP, Arora R.Immediate and delayed effects of successful percutaneous transvenous mitral commissurotomy on global right ventricular function in patients with isolated mitral stenosis. Int J Cardiol 1999;68: 217-23.

26. Schattke S, Knebel F, Grohmann A, Dreger H, Kmezik F, Riemekasten G, Baumann G and Borges AC. Early right ventricular systolic dysfunction in patients with systemic sclerosis without pulmonary hypertension: a Doppler Tissue and Speckle Tracking echocardiography study.Cardiovascular Ultrasound 2010, 8:3doi:10.1186/1476-7120-8-3.

27. Lee TM, Su SF,Chen MF, Liau CS, Lee YT.Changes of left ventricular function after percutaneous balloon mitral valvuloplasty in mitral stenosis with impaired left ventricular performance. Int J Cardiol 1996; 25:211-55.

28. Borer JS,Hochreiter C, Rosen S.Right ventricular function in severe non-ischemic mitral insufficiency. Eur Heart J 1991;12:22-5.

29. Malhotra V, Beohar PC, Gondal R, Kaul UA, Khanna SK. An autopsy study of rheumatic heart disease. Part II. Associated findings. Jpn Heart J 1987;28: 7-14.

30. Iskandrian AS,Hakki AH,Ren JF,Kotler MN,Mintz GS, Ross J,et al.Correlation among right ventricular preload, afterload and ejection fraction in mitral valve disease: radionuclide, echocardiographic and hemodynamic evaluation. J Am Coll Cardiol 1984;3:1403-11.

31. Sreeram G, Padmakumar R, Krishnamoorthy KM, Sivasankaran S,et al.Effect of a Successful Balloon Mitral Valvotomy on Ventricular Function as Assessed by Tissue Doppler Evaluation. Indian Heart Journal. Sept-Oct, 2003; 55:(5)Article No. 288.

32. Mehta V,Mukhopadhyay S,Yusuf J, Sengupta PP, Rastogi V, et al.Acute Effects of Percutaneous Transvenous Mitral Commissurotomy on Right Ventricular Function in Rheumatic Mitral Stenosis: A Tissue Doppler Echocardiographic Study.Indian Heart Journal. Sept-Oct, 2003; 55:(5)Article No. 83.

33. Samad BA, Alam M, Jensen-Urstad K. Prognostic impact of right ventricular involvement as assessed by tricuspid annular motion in patients with acute myocardial infarction. Am J Cardiol 2002; 90:778–781.

34. Forfia PR, Fisher MR, Mathai SC, Housten-Harris T, Hemnes AR, Borlaug BA, Chamera E, Corretti MC, Champion HC, Abraham TP, Girgis RE, Haussoun PM. Tricuspid annular displacement predicts survival in pulmonary hypertension. Am J Respir Crit Care Med 2006;174:1034–1041.

35. Cruz-Gonzalez I, Sanchez-Ledesma M, Sanchez PL, Martin-Moreiras J, Jneid H, Rengifo-Moreno P. Predicting success and long-term outcomes of percutaneous mitral valvuloplasty: a multifactorial score. Am J Med. 2009 Jun;122(6):581.e11-9.

36. Hernandez R, Banuelos C, Alfonso F, et al. Long-term clinical and echocardiographic follow-up after percutaneous mitral valvuloplasty with the Inoue balloon Circulation 1999;99:1580-1586.

37. Palacios IF, Sanchez PL, Harrell LC, Weyman AE, Block PC. Which patients benefit from percutaneous mitral balloon valvuloplasty? Prevalvuloplasty and postvalvuloplasty variables that predict long-term outcome. Circulation 2002;105:1465-1471.

38. Ozdemir K, Altunkeser BB, Gok H, Içli A, Temizhan A. Analysis of the myocardial velocities in patients with mitral stenosis. J Am Soc Echocardiogr. 2002;15: 1472-8.

39. Arslan S, Buyukkaya S, Gundogdu F, Sevimli S, Buyukkaya E, Aksakal E, et al. Assessment of right ventricular functions by tissue Doppler echocardiography in patients with rheumatic mitral valve stenosis associated with sinus rhythm or atrial fibrillation. Türk Kardiyol Dern Arş. 2007;35:475-81.